PRELIMINARY RESULTS OF THE HAWAII KALINA CYCLE® FEASIBILITY ANALYSIS

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PRELIMINARY RESULTS OF THE HAWAII KALINA CYCLE® FEASIBILITY ANALYSIS

- Introduction
  - What is Kalina Cycle?
  - Comparison to Rankine Cycle
- Historical Applications
  - California, Iceland & Japan
- Identification of Promising Hawaii Applications
- Conclusions

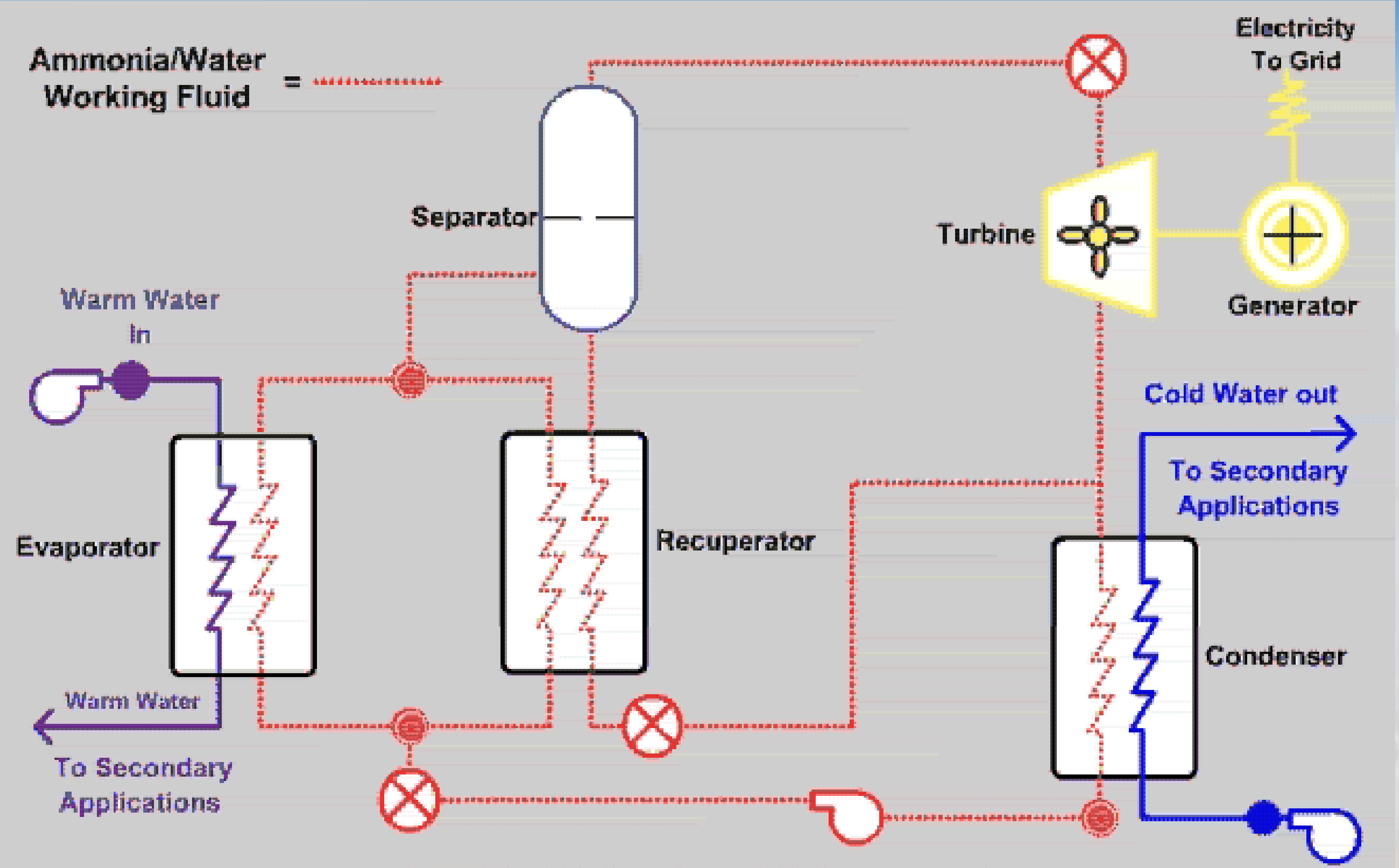
The Kalina Cycle®

- Binary Energy Conversion Cycle which uses Ammonia/Water Mixture as the Working Fluid

- Variable Mixture (Concentration Changes Throughout the Cycle) - Allows Working Fluid to Efficiently Match the Characteristics of the Resource

Ideal for Low Temperature/Bottoming Cycle Applications

Simplified Kalina Cycle®

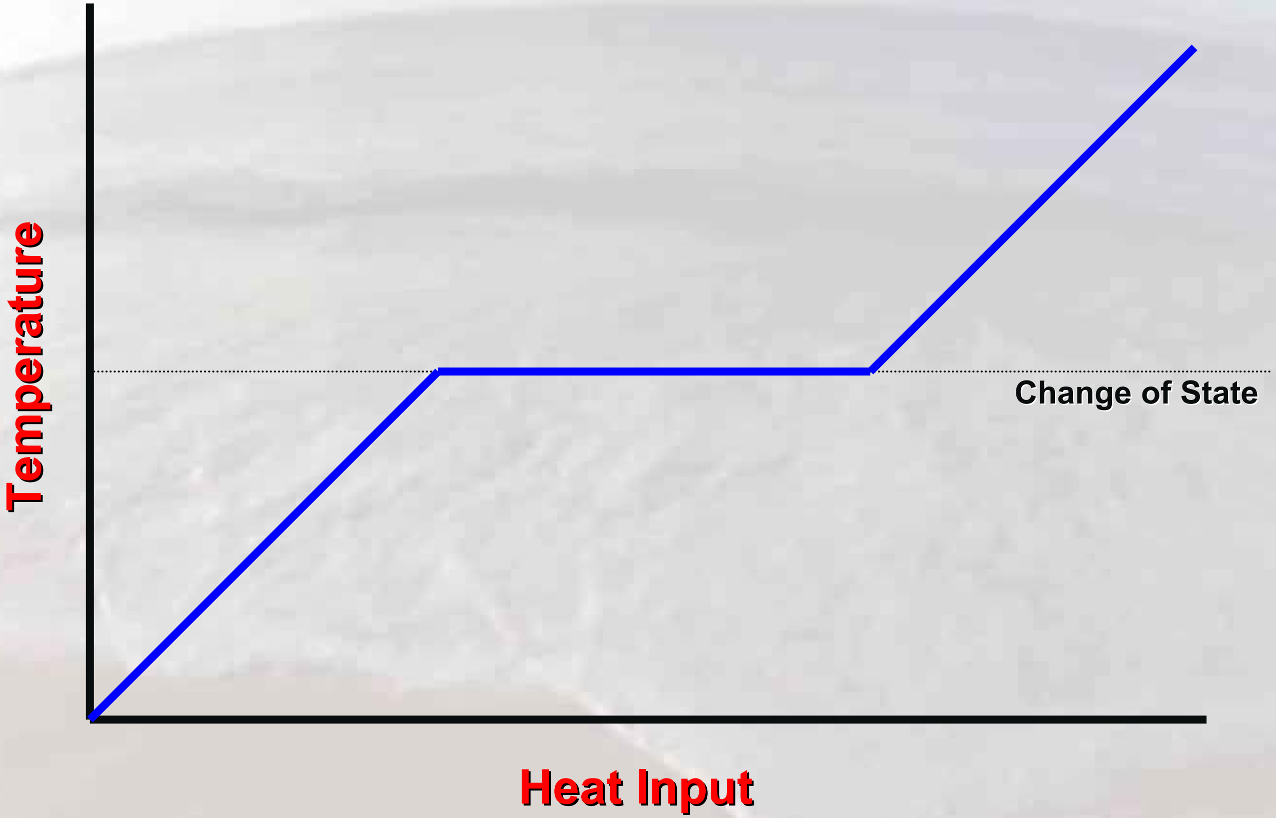


Simplified Kalina Cycle™ (Exergy,Inc.)

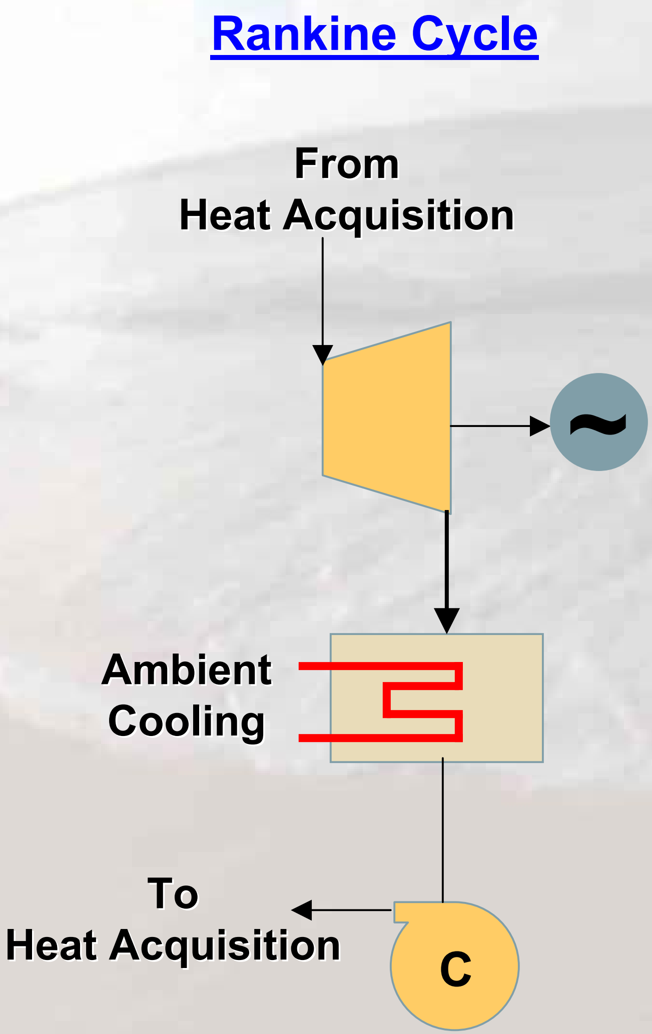
Ammonia/Water Safety Concern?

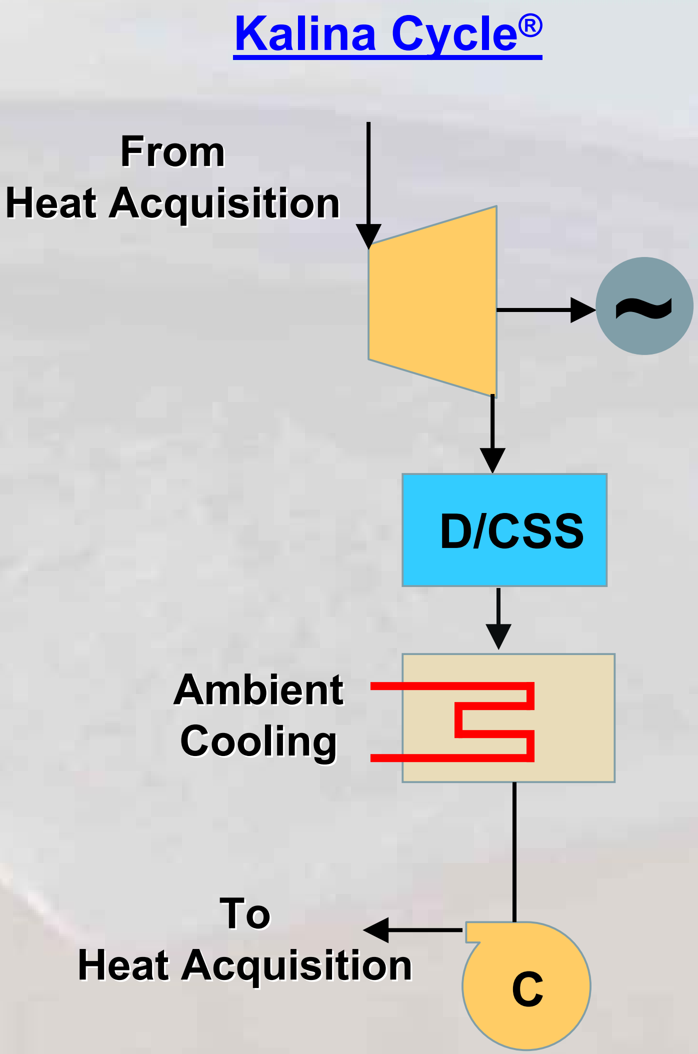
- Needs to be Used Carefully
  - Not Classified as Hazardous
- Less Hazardously Flammable than more Conventional Working Fluids
- Comparatively Environmentally Benign
- Ammonia Vents Easily, is Self-Alarming

Single Working Fluid Thermodynamic Limitation



Simplified Comparison of Rankine Cycle to Kalina Cycle®





Source: Recurrent Resources, Inc.

Operational Kalina Cycle® Plants

3.5 MW Kalina Cycle® Plant
Canoga Park, CA

Courtesy: Exergy

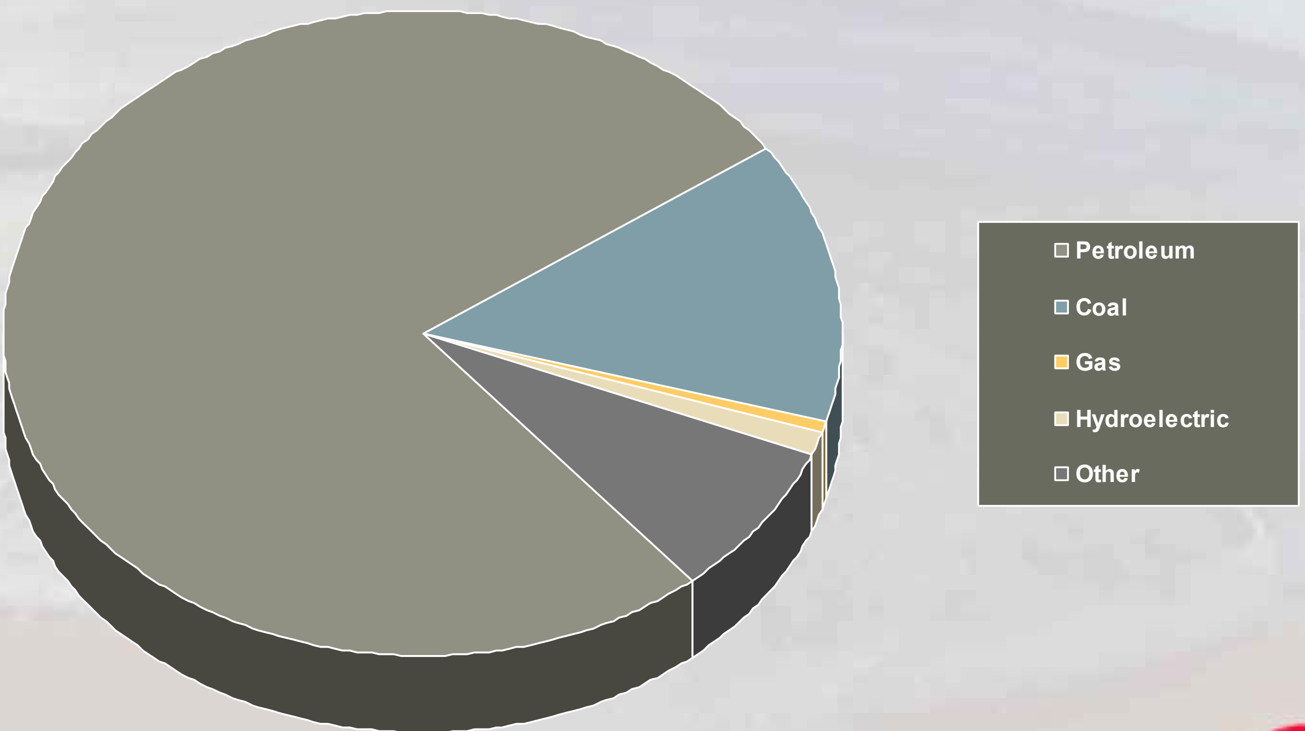
Courtesy: Exergy

2 MW Kalina Cycle® Plant
Husavik, Iceland

Husavik Geothermal Plant
“First Two Years”

- Demonstrated High Reliability (Availability Rated in the High 90%)
- Operates Successfully Largely Unattended
- Proved to be Quiet, Sturdy with no Odor

Energy Generation by Source, 1999



Source: Energy Information Administration

Ten Largest Plants by Generating Capacity, 1999

Plant	Primary Energy Source(s)	Operating Company	Net Summer Capability (MW)
1. Kahe	Petroleum	Hawaiian Electric Co.	582
2. Waiau	Petroleum	Hawaiian Electric Co.	457
3. Kalaeola Co-gen	Petroleum	Kalaeloa Partners LP	261
4. AES Hawaii, Inc.	Coal	AES Hawaii, Inc.	189
5. Maalaea	Petroleum	Maui Electric Co.	168
6. Honolulu	Petroleum	Hawaiian Electric Co.	100
7. Port Allen	Petroleum	Kauai Island Utility Co-op	97
8. H-Power	Waste	DFO Partnership	61
9. Hawaiian Com& Sugar	Coal	Hawaiian Coml& Sugar	58
10. W H Hill	Petroleum	Hawaiian Electric Light Co.	35

Source: Energy Information Administration

Residues/Pollutants/Effects (qualitative)

	Coal	Oil	Natural Gas	Biomass/ Waste	Nuclear Energy	Solar Energy
CO						
CO_2						
C_nH_m						
NO_x						
SO_2 (Plaster)						
Dust (soot)						
Ash						
Radioactivity						
Heavy Metals						
Waste Heat						
Material Intensity						
Albedo						
Water Vapor						

Courtesy: Center for Solar Energy and Hydrogen Research

How Much Waste Heat in Hawaii?

- ~ 9 billion kW_h/yr Electricity from Fossil Fuels

  (Hawaii Data Book)

- Conservative Estimate:
  - From Stack Gases: ~ 356 million kW_h/yr
  - From Cooling Water: ~ 534 million kW_h/yr
  - Total: ~ 890 million kW_h/yr (~10% of Total Production!)

The Waste Heat Potential in Hawaii is Quite Significant!

Estimates Courtesy of Dr. Rezachek, DBEDT

Petroleum/Diesel Power Plants

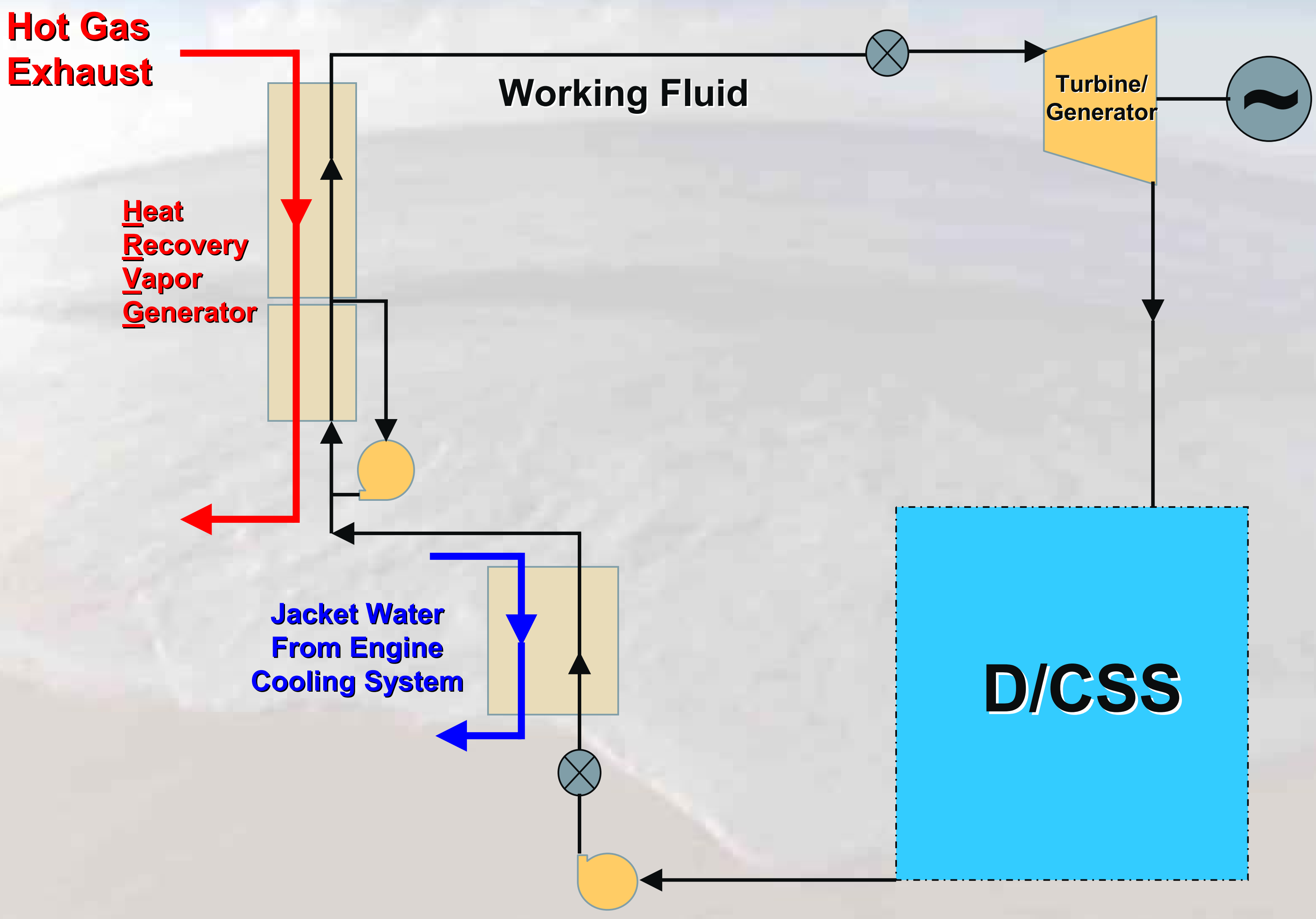
Courtesy: HECO

Kahe Power Plant - Oahu

Maalea Power Plant - Maui

Courtesy: MECO

Simplified Conceptual Flow Diagram for Diesel Combined Cycle



Source: Recurrent Resources, Inc.

Peak Design Capacity for Diesel Combined Cycle / Bottoming Cycle Depends Upon:

- Diesel exhaust gas temperature and flow
- Fuel sulfur content (limits the min. stack temp.)
- Type of cooling available (water or air cooled)
- Capacity of diesel generating station
- Site ambient conditions
- Diesel back pressure requirements
- Bottoming cycle design

Design Capacity Comparison: Kalina Cycle® vs. Rankine Steam Bottoming Cycle

First Case Study:

Kohinoor Energy Ltd. – Pakistan

8x Wartsila 18V46 diesel units

- Existing Rankine Bottoming Cycle = ~ 8 MW_{net}
- Initial Kalina Cycle® Design = ~ 13.3 MW_{net} (+66%)
- Optimized Kalina Cycle Design = ~ 16.0 MW_{net} (+100%)

Second Case Study:

Kohinoor Energy Ltd. – India

4x Wartsila 12V46 diesel units

- Design Rankine Bottoming Cycle = ~ 1.87 MW_{net}
- Kalina Cycle® Design = ~ 3.24 MW_{net} (+73%)

Case Study Example: Turkey
Basic Assumptions

- 100 MW capacity (PPA ~ 876 million kWh/yr)
- Man B&W 18-V-48/60 diesel unit (18.39 MW)
- Three competing scenarios:
  - 7 DG units, no bottoming cycle, one DG in standby
  - 6 DG units, no bottoming cycle, no DG standby
  - 6 DG units, Kalina Bottoming Cycle ® (11 MW), no DG standby

Case Study: Turkey Basic Assumptions (con.)

- Capital Costs
  - DG Station ($650/kW)
  - Kalina Cycle® ($1200/kW)
- O&M Costs
  - DG Station ($0.01/kW$_{hr}$)
  - Kalina Cycle® ($0.005/kW$_{hr}$)
- Fuel Costs ($0.20/kg)

Source: Recurrent Resources, Inc.

Case Study Summary

Comparison/ Analysis	6 DG & KCC	6 DG Only	7 DG Only
Annual Generation	876 million kW_{hr}	835 million kW_{hr}	876 million kW_{hr}
Annual Gross Revenue	56.94 \$million	54.3 \$million	56.9 \$million
Annual Fuel Cost	28.47 \$million	29.85 \$million	31.36 \$million
Annual Lube Oil Cost	1.00 \$million	1.04 \$million	1.10 \$million
Annual O&M Cost	8.32 \$million	8.35 \$million	8.76 \$million
Total Operating Cost (\$/yr)	37.78 \$million	39.25 \$million	41.22 \$million
Total Operating Cost (\$/kW_{hr})	0.043 \$/kW_{hr}	0.047 \$/kW_{hr}	0.047 \$/kW_{hr}
Capital Charge	0.015 \$/kW_{hr}	0.013 \$/kW_{hr}	0.014 \$/kW_{hr}
Total Generation Cost (\$/kW_{hr})	0.058 \$/kW_{hr}	0.060 \$/kW_{hr}	0.061 \$/kW_{hr}
Gross Operating Profit	19.16 \$million	15.05 \$million	15.72 \$million
Kalina Cycle Payback Period	--	3.2 years	0.4 years
Simple Return on Investment	22.5%	21.0%	18.8%

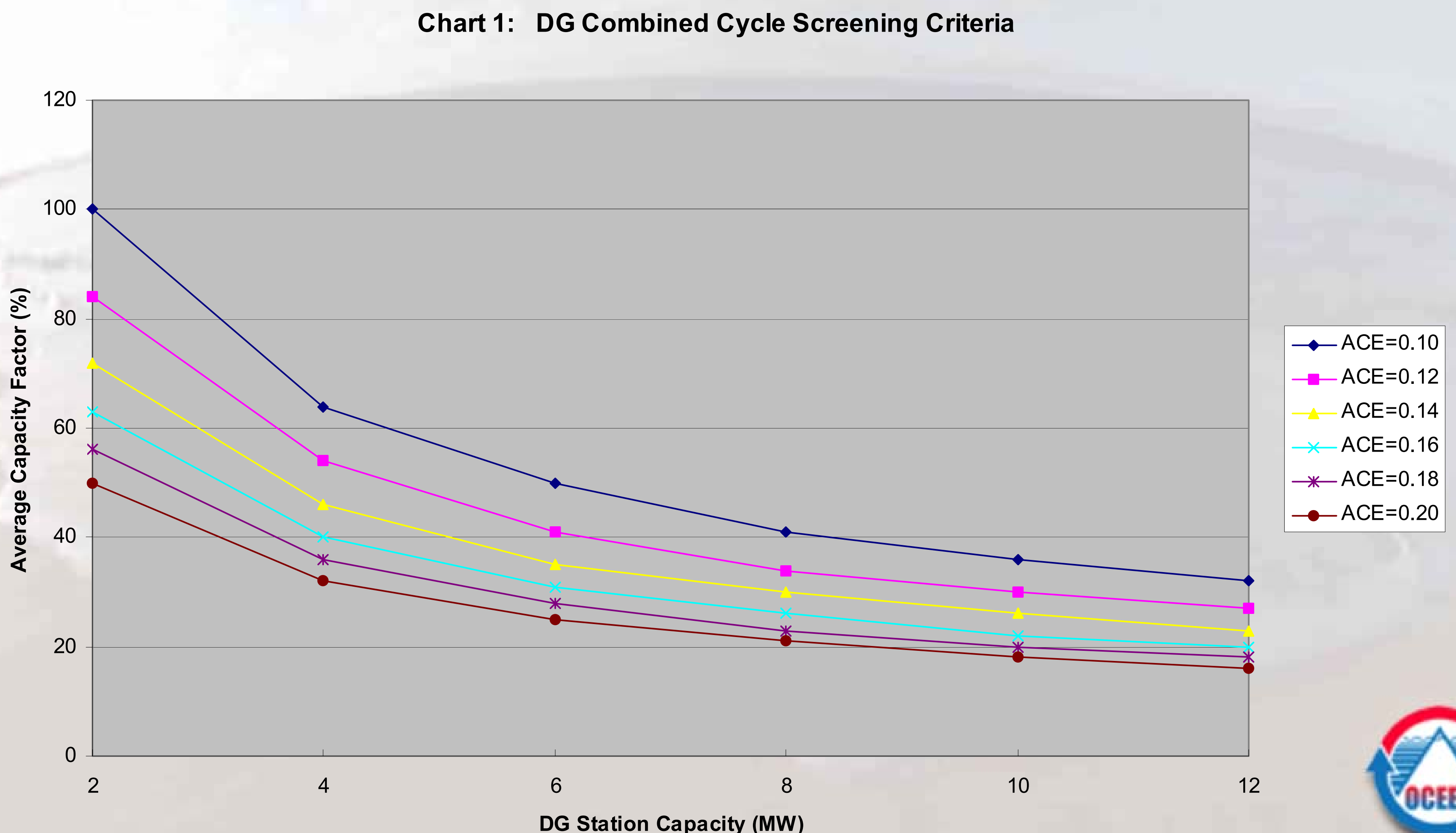
Economics of Bottoming Cycles for Large Diesel Generation Stations

- Capital Costs:
  - Kalina Cycle® less than Rankine Bottoming Cycle ($/kW)
  - Kalina Cycle ® more than diesel generation power plant
- Savings in fuel cost more than makes up for additional capital
  - Savings on fuel is dependent upon fuel type
- Include impact of standby diesel generation capacity for frequent diesel unit maintenance

Economic Viability of Adding Kalina Bottoming Cycle to Existing Diesel Generation Station:

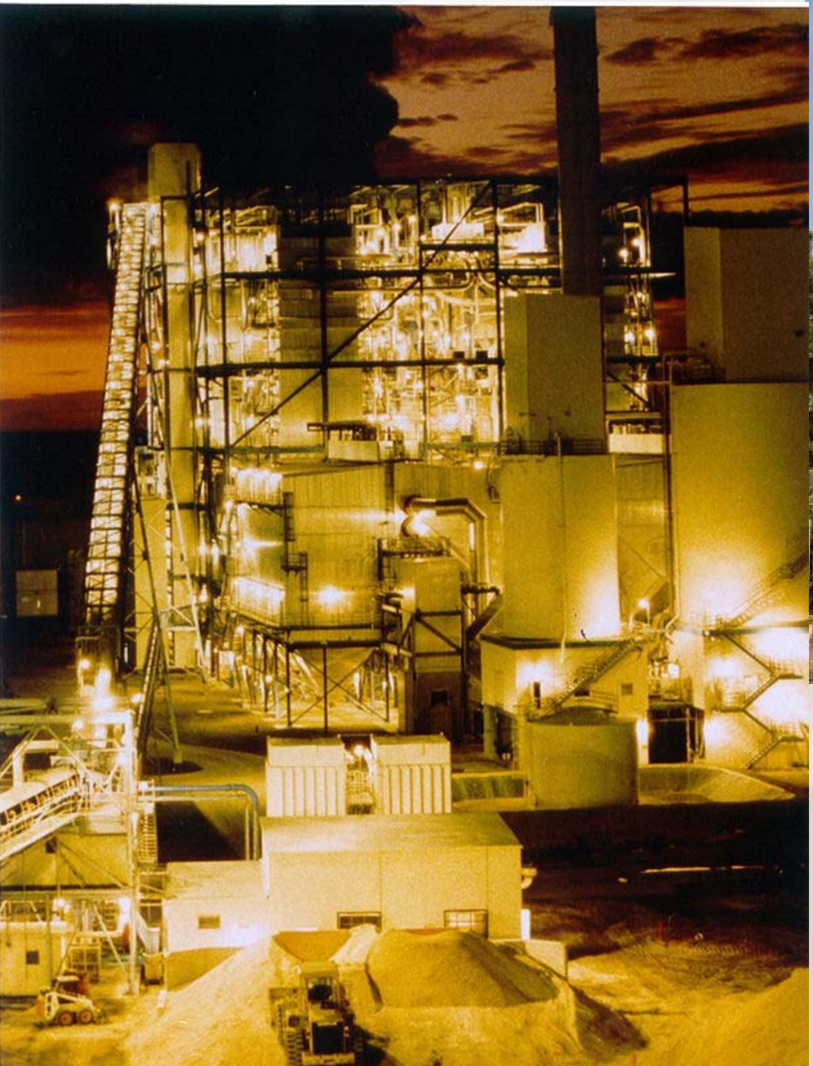
- Size of the Diesel Station
- Number and Capacity of Each Diesel Unit
- Diesel Unit Annual Average Capacity Factor
- Diesel Unit Exhaust Heat Rejection
- Capital Cost of the Kalina Bottoming Cycle Power Plant
- Avoided Cost of Energy (Purchased Energy Tariff or cost of fuel and O&M)
- Kalina Cycle Power Plant O&M
- Escalation Assumptions
- Discount Rate or Cost of Capital
- Debt Assumptions
- Tax Assumptions

Diesel Generation Combined Cycle Screening Criteria



Courtesy: Exergy, Inc.

Coal Burning Facilities



AES Hawaii, Inc. - Oahu

Biomass/Waste Power Plants

Courtesy: HECO

Biomass Power Plant – Maui

Courtesy: HECO

H-Power Plant – Oahu
(Waste)

Large Industrial Facilities

Courtesy: Tesoro

Tesoro Power Plant - Oahu

Tesoro Refinery - Oahu

Courtesy: Tesoro

Geothermal Power Plants

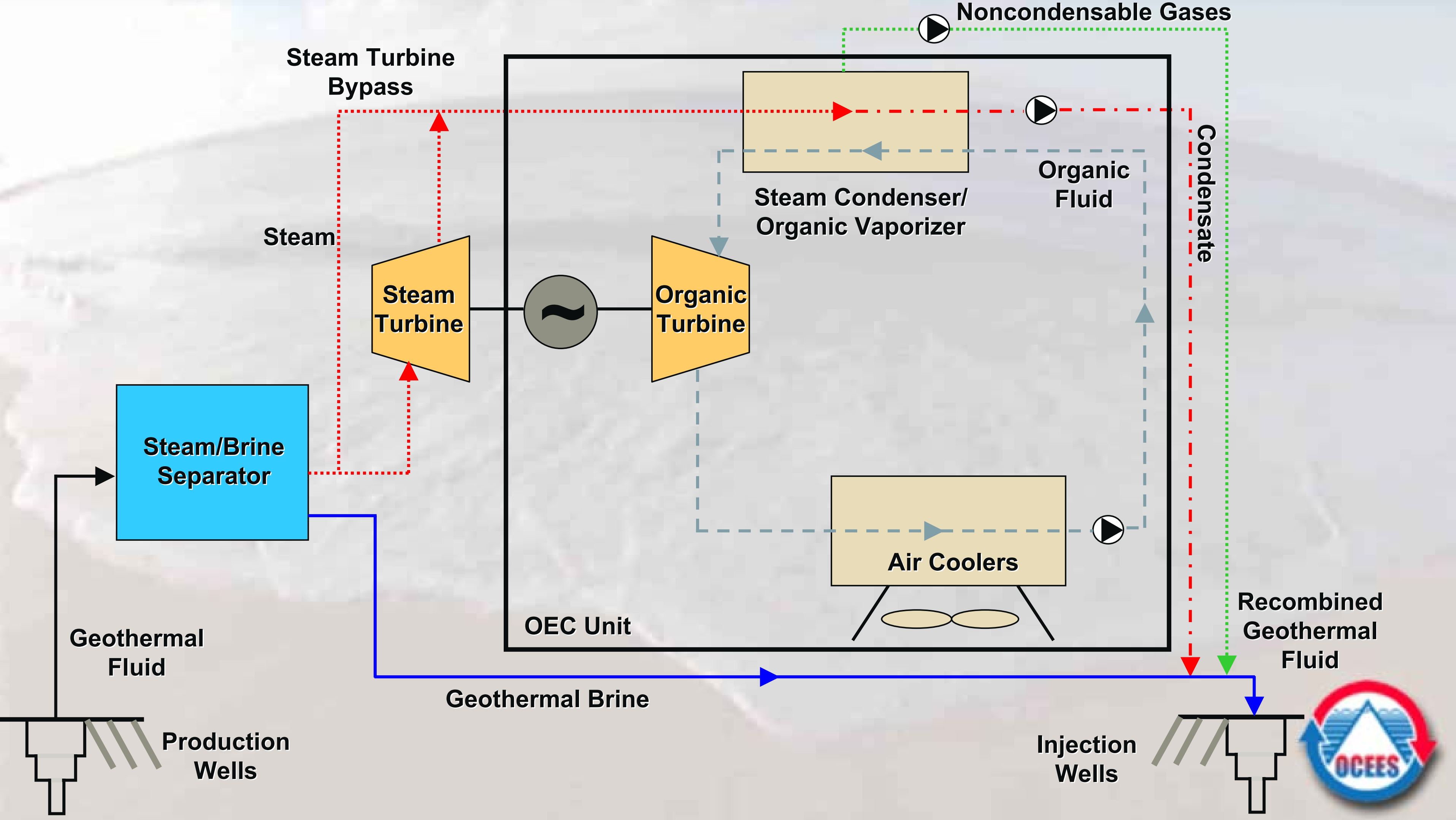
Courtesy: HECO

Recent Lava Flow - Hawaii

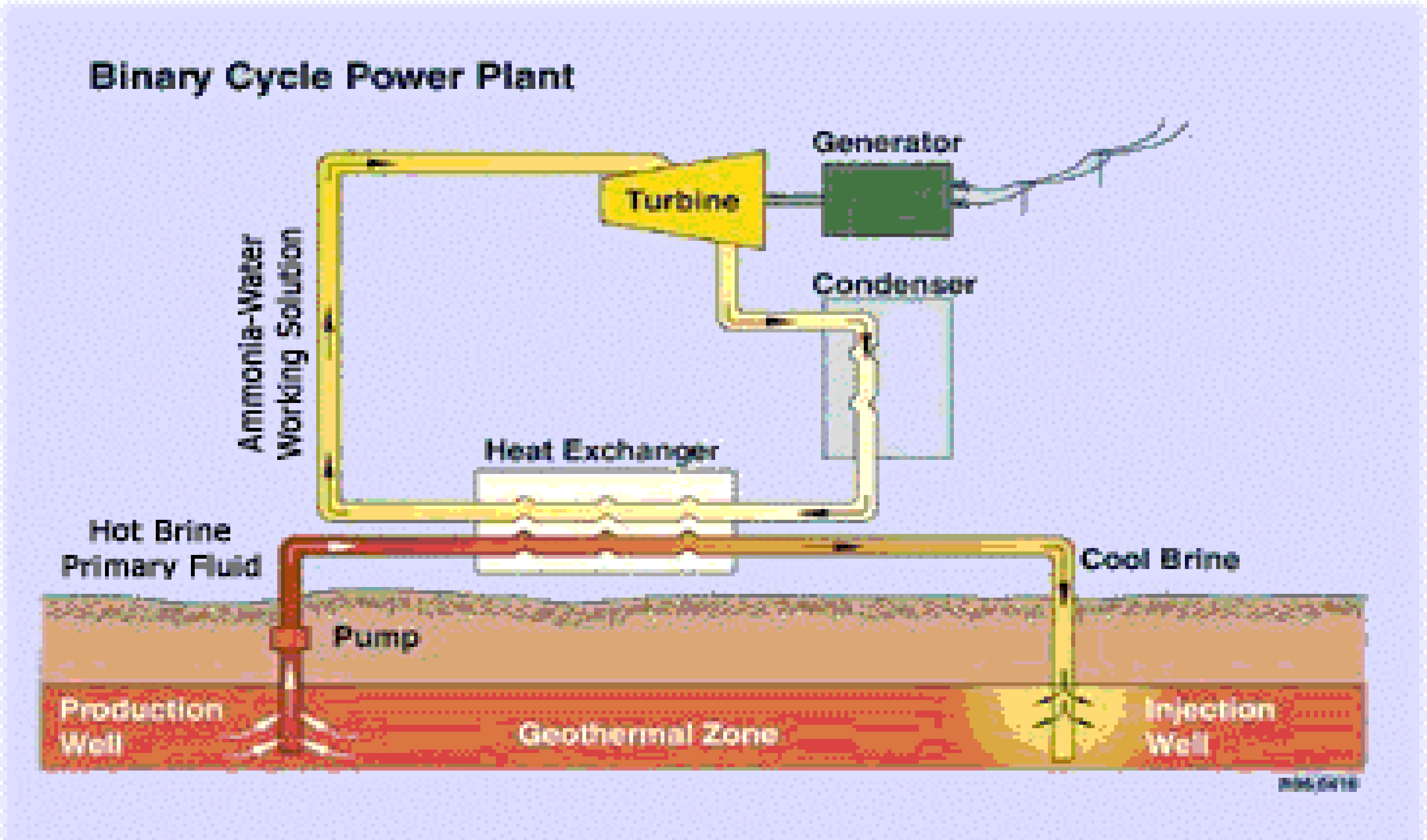
Puna Geothermal Venture - Hawaii

Courtesy: HECO

Schematic of the Puna Geothermal Venture Facility



Simple Schematic of Binary Cycle in Geothermal Configuration



Courtesy: Advanced Thermal Systems

Husavik/Puna Resource Comparison

Husavik: Brine Flow - 90 l/s @ 121 °C

CW Flow – 180 l/s @ 4 °C

Power Generated = 1.7 MW_{net}

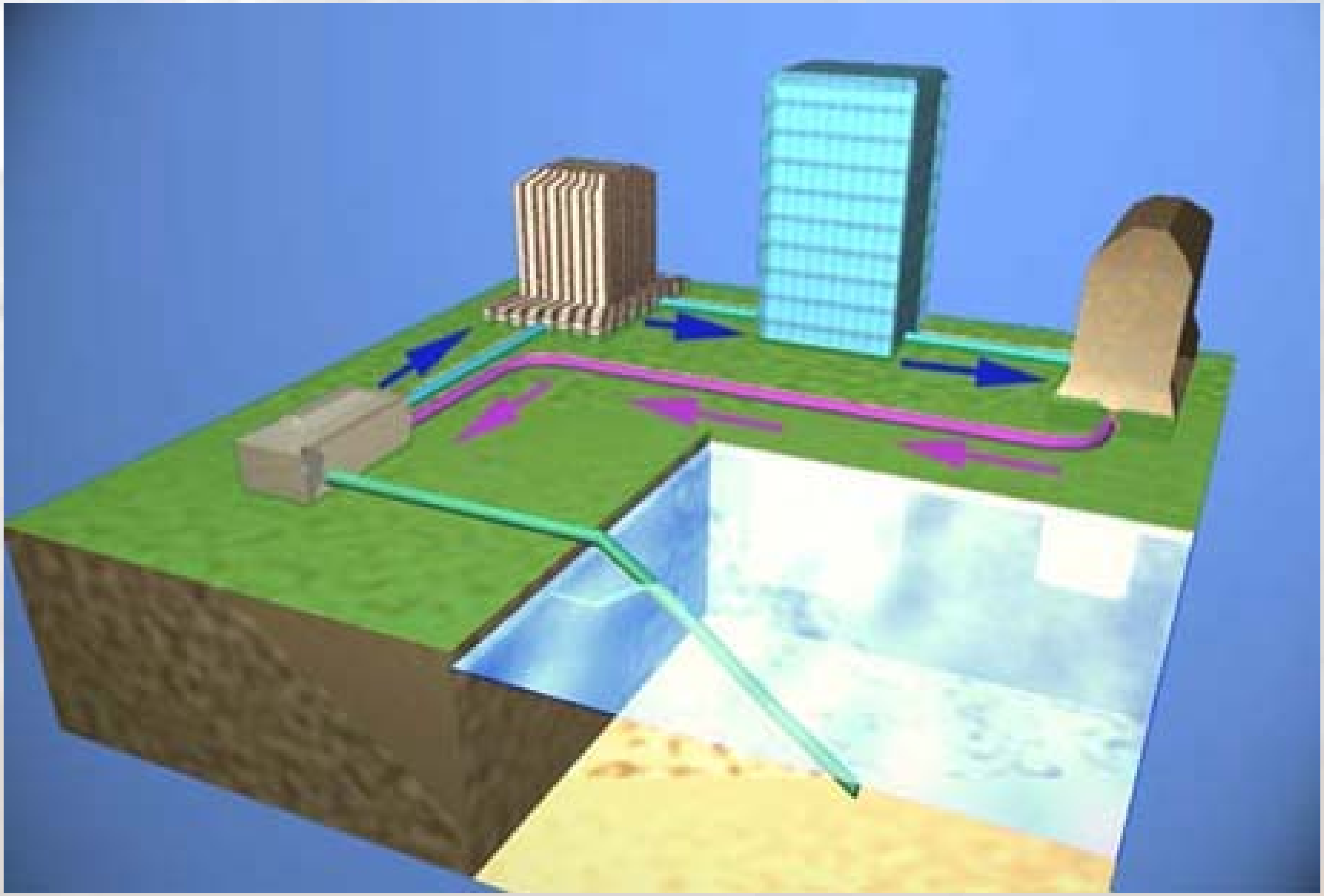
Total Cost $1,875,000 ($905/kW)

Puna: Brine Flow – ~189 l/s @ 149 °C

CW Flow - ~85 l/s @ 40.6 °C

Air Cooling? Ocean Water?

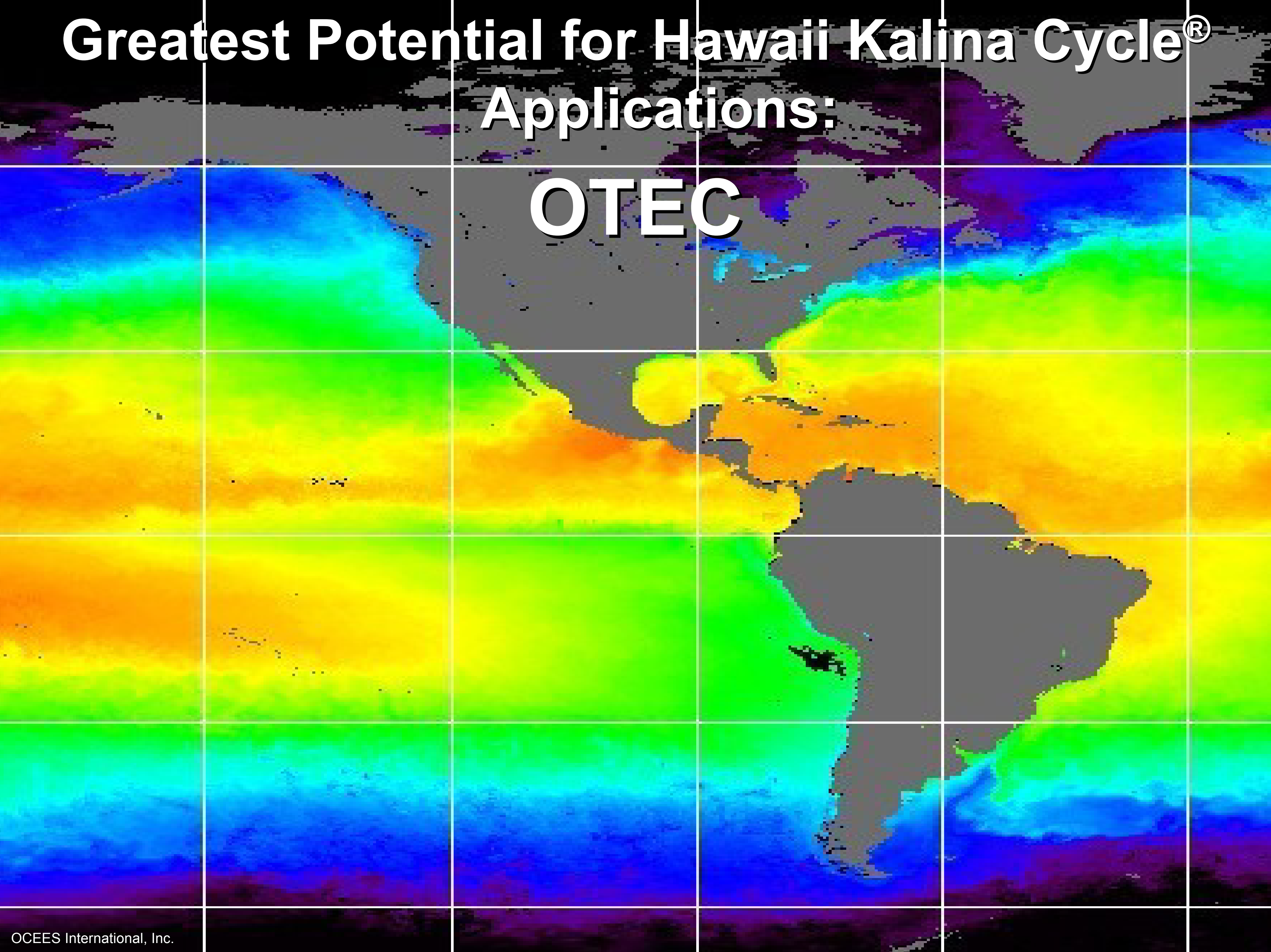
Used in Conjunction with Local Power Plant and Seawater Air Conditioning (SWAC) Facility



Providing the Power Cycle for OTEC Applications!

Greatest Potential for Hawaii Kalina Cycle® Applications:

OTEC



Predicted Heat Rate/Efficiency Gains by Power Plant Technology

- **Geothermal Plants:** ~ 30 – 50 %
- **Coal/Biomass/ Waste Plants:** ~ 20%
- **Diesel/ Petroleum Plants:** ~ 10 – 15%
- **OTEC Plants:** ~ 50 + %

Conclusions:

- Kalina Cycle® is Superior Technology to Traditional Rankine Cycle for Low Temperature/Bottoming Cycle Applications
- Hawaii has Significant Waste Heat Resources for Potential Kalina Cycle® Integration
- Integration Makes Good Environmental and Economic Sense Under Amenable Conditions
- Further Analysis for Specific Identified Applications is Warranted